REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-04-

0051

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
08/27/03	Final	5/01/2001 - 4/30/2003

4. TITLE AND SUBTITLE

Very Low Temperature Measurement System for Quantum Computation with Superconductors

5a. CONTRACT NUMBER

5b. GRANT NUMBER
F49620-01-1-0351

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Prof. Terry P. Orlando

20040203 019

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Research Laboratory of Electronics
Massachusetts Institute Of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
801 North Randolph Street
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution Statement A: APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Two dilution refrigerators have been installed and made operational for the purpose of having dedicated measurement systems one at MIT and the other at the University of Rochester for carrying out quantum computing experiments. Both systems are a Kelvinox 400 model from Oxford instruments, equipped with both dc and rf lines for measurements; and both systems are vibrationally isolated and magnetically and electrically shielded for low noise measurements. Within the first year these systems have been fitted with custom-designed sample spaces and wiring. Within less than a year, this equipment has enabled the researchers to demonstrate: quantum levels in a persistent current qubit, rf and dc spectroscopy of these energy levels, and control circuits using Single Flux Quantum circuits. This equipment is enhancing our research effort to study, design, demonstrate, and develop algorithms and quantum-coherent circuitry using magnetic-flux-based superconducting qubits.

15. SUBJECT TERMS

Quantum Computing, Low Noise, Quantum circuits, superconducting qubits.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
U	U	U	UL		

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Final Report for the Durint Equipment Proposal: Very Low Temperature Measurement System for Quantum Computation with Superconductors AFOSR Grant F49620-01-1-0351

By
T.P. Orlando, S. Lloyd, L. Levitov , J. E. Mooij, Massachusetts Institute of Technology;
Mark Bocko, Mark Feldman, University of Rochester;
and M. Tinkham, Harvard University

I. Abstract

Two dilution refrigerators have been installed and made operational for the purpose of having dedicated measurement systems one at MIT and the other at the University of Rochester for carrying out quantum computing experiments. Both systems are a Kelvinox 400 model from Oxford instruments, equipped with both dc and rf lines for measurements; and both systems are vibrationally isolated and magnetically and electrically shielded for low noise measurements. Within the first year these systems have been fitted with custom-designed sample spaces and wiring. Within less than a year, this equipment has enabled the researchers to demonstrate: quantum levels in a persistent current qubit, rf and dc spectroscopy of these energy levels, and control circuits using Single Flux Quantum circuits. This equipment is enhancing our research effort to study, design, demonstrate, and develop algorithms and quantum-coherent circuitry using magnetic-flux-based superconducting qubits.

II. Experimental Equipment

Two dilution refrigerators have been installed and made operational for the purpose of having dedicated measurement systems one at MIT and the other at the University of Rochester for carrying out quantum computing experiments. Both systems are a Kelvinox 400 model from Oxford instruments, equipped with both dc and rf lines for measurements; and both systems are vibrationally isolated and magnetically and electrically shielded for low noise measurements. Within the first year these systems have been fitted with custom-designed sample spaces and wiring. Within less than a year, this equipment has enabled the researchers to demonstrate: quantum levels in a persistent current qubit, rf and dc spectroscopy of these energy levels, and control circuits using Single Flux Quantum circuits. This equipment is enhancing our research effort to study, design, demonstrate, and develop algorithms and quantum-coherent circuitry using magnetic-flux-based superconducting qubits.

Each dilution refigerator has the following standard features:

Kelvinox 400 System

- KEL400SYS1 base system
- Vapor Shield Dewar SMD10/15VSEX
- Sliding Seal KEL400SS
- Support system MSSSMD
- HCT helium cooled trap
- Transfer tube TTN2F
- Helium mixture HE3400
- Calibrated temperature sensor
- 2 x's 24-way connector, with copper wires
- Flexible co-axis cables
- Helium level detector
- Sample holder LECSH

The two systems were purchased from
Oxford Instruments America, Inc
130A Baker Ave.
Concord, MA 01742
Tel: 978-369-9933
FAX: 978-369-6616
Email: info@ma.oxinst.com
www.oxford-instruments.com

II.1. The MIT System

The MIT system is suspended on a vibrational table which was custom-made by
Integrated Dynamics Engineering, Inc
377 University Ave.
Westwood, MA 02090
Tel: 781-326-5700
Fax: 781-326-3004
email:mike.fraumeni@ideworld.com
www.ideworld.com

The dilution refrigerator supported by its vibrational table is shown below:

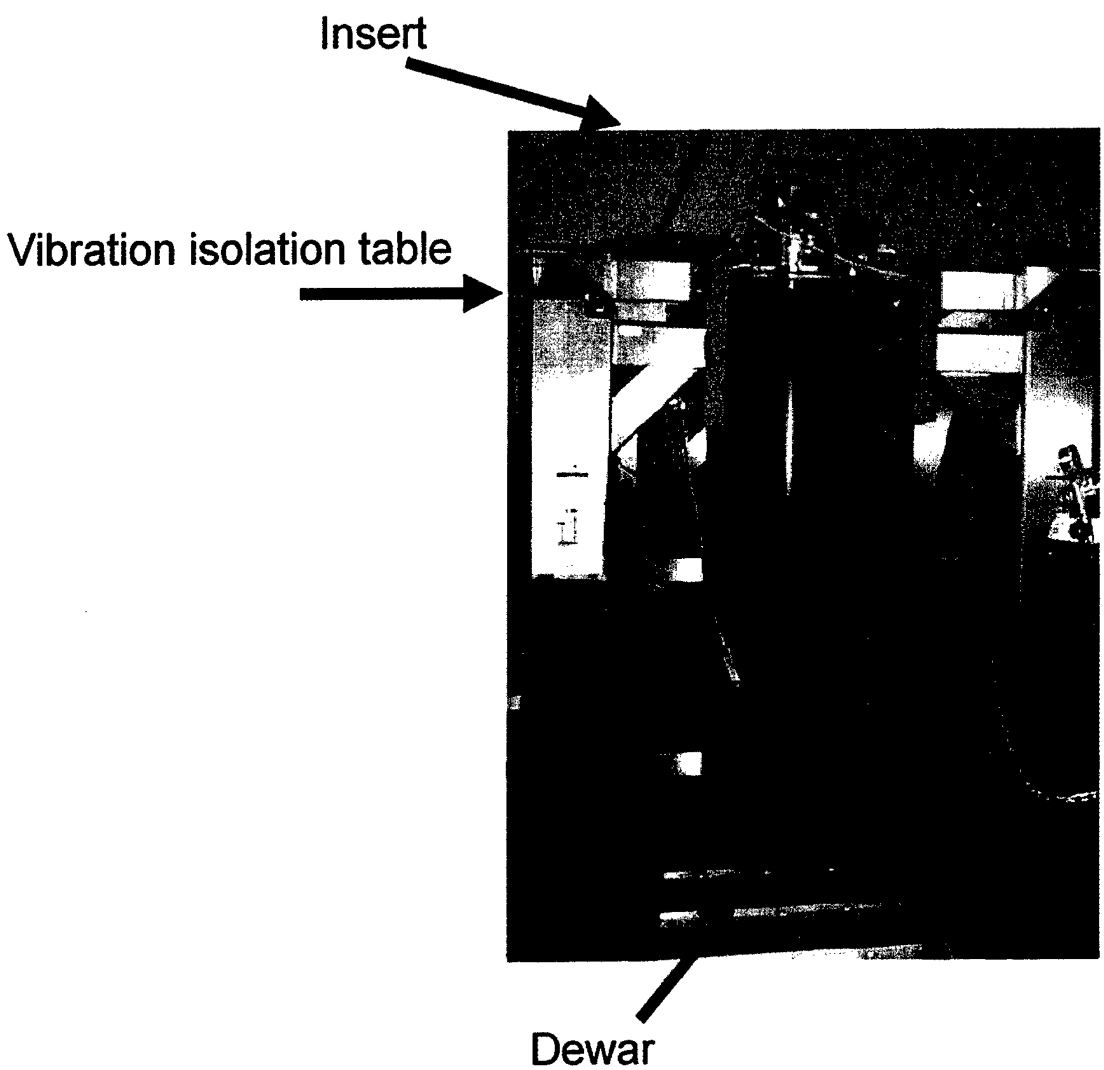
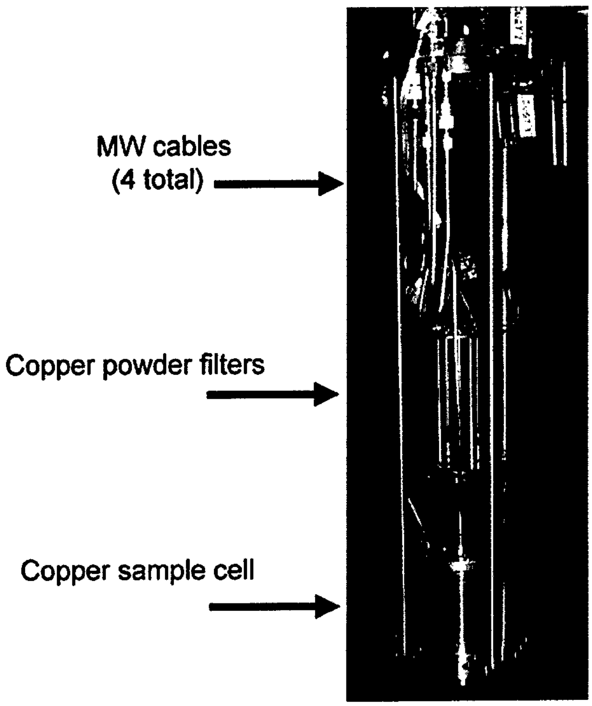


Figure 1. Vibrational table holding the Dilution Refrigerator

Additionally each of the 24 dc lines were specially filtered with homemade cooper powder filters which were installed to operate at cryogenic temperatures. A sample space was specially designed to minimize electromagnetic noise; especially because it was decided in the MIT system not to enclose the dilution refrigerator in a screened room. A triple layer permalloy magnetic shields were installed to operate in the liquid helium environment.



The Dilution refrigerator part of the Kelvinox 400, showing the custom-made parts: the microwave cables, copper powder filters, and the sample cell.

II.2 The University of Rochester System

The University of Rochester system is enclosed in a shielded room, provided by Lindgren Inc., and is supported on a home-built vibration isolation platform employing Newport Inc. pneumatic isolators. The dewar extends into a 4' deep pit in the floor of the shielded room (also shielded) and the height of the room allows for easy removal and access to the probe. The system is shown below in Figure 3.

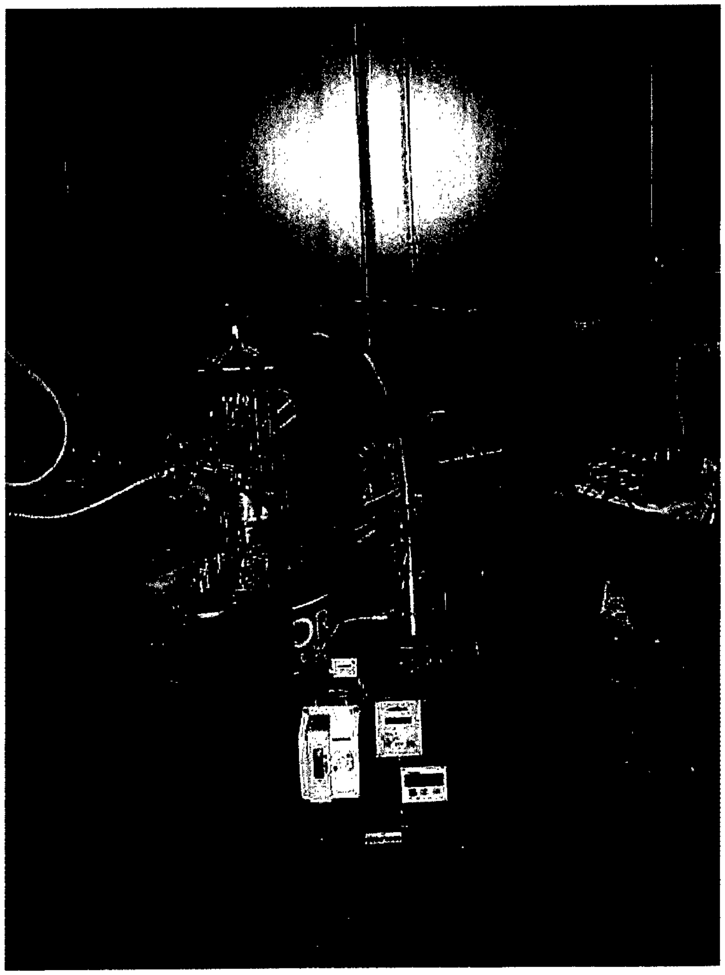


Figure 3. University of Rochester dilution refrigerator system.

The Rochester unit was purchased with 48 low frequency lines and 2 wide-band coax lines installed by the Oxford factory. Copper powder filters of a standard design have been installed on a subset (6) of the low frequency lines and a flip-chip mounting fixture has been installed mounted to the mixing chamber in the refrigerator. A triple layer mu-metal shield that will be mounted in the inner vacuum chamber of the unit has been designed and will be installed shortly, upon its receipt.

A base temperature of 9.5 mK was demonstrated in the commissioning of the unit and operation of RSFQ circuits at temperatures of approximately 20 mK has been achieved subsequently. The system has proven to be reliable and straightforward to use.